Nonlinear Phenomena in Complex Systems, vol. **17**, no. 4 (2014), pp. 409 - 416

Relativistic Motion of the Test Body in Photogravitational Field of Star: Application to the Solar System

A. P. Ryabushko
Belarusian National Technical University, Minsk, BELARUS

I. T. Nemanova, T. A. Zhur, I. P. Boyarina
Belarusian State Agrarian Technical University, Minsk, BELARUS

O. L. Zubko*
Department "Higher Mathematics No.1", Belarusian National Technical University, 65 Nezavisimosti Ave., 220013 Minsk, BELARUS
(Received 05 September, 2014)

The regularities of the motion for every test body in photogravitational field of a star, which can significantly differ from the regularities of motion of a body in gravitational field, have been obtained. The following effects of STR and GTR to the terms of order v^2/c^2 have been considered: the light pressure, the Poynting-Robertson effect, the longitudinal and transverse Doppler effect, the increase in mass of the moving test body, the effects of the space-time curvature which arise due to the gravitational fields of the star and gas-dust ball surrounding the star. We have showed that the longitudinal Doppler effect and the aberration of light (the effects of order v/c) lead to the spiral motion of the test body around the star. Taking into account other effects of order v^2/c^2 accelerates approximately by factor two the body fall on the spiral onto the star. The spiral can be seen as the decreasing in size ellipse with decreasing eccentricity and periastron, which can shift against the motion in orbit due to the influence of the gravitational field of gas-dust ball.

PACS numbers: 04.25.D-, 03.30.+p, 04.25.-g, 42.50.Wk, 95.30.sf, 98.80.jk, *43.28.Py
Keywords: field, spiral motion, windage of the test bodies, time of fall on the star

Introduction

The relevance of the research is caused by the need for more accurate forecast of the movement of small bodies in the solar system (asteroids, comets, meteorites, dust particles, space vehicles and stations, possibly with a solar sail, etc.) due to intensive development of near and deep space, as well as to solve some cosmogonic problems of planetary systems.

Relativistic motion of bodies without considering light pressure has been studied for many years by Belarusian and Kazakh science schools on the problem of motion of bodies (see e.g., [1]–[9] and the references therein). These science schools used different methods for investigation such e.g. as the method of Einstein–Infeld [10, 11] and Fock method [12].

Light pressure in the theory of motion of bodies presumes the use of photogravitational field of laws of electrodynamics, which are based on covariant Maxwell equations and special relativity theory (SRT). One should consider the following SRT effects: (i) relativistic change in mass of the body moving relative to the observer, (ii) relativistic change in the electromagnetic radiation of the star (light pressure) acting on the body in accordance with the longitudinal and transverse Doppler effect, (iii) Lorentz contraction of the midsection of the body, (iiii) the aberration of light. From all the effects listed in papers [13]–[15] and papers of other authors, only the aberration of light and light pressure of the star effects have been considered before. The aberration of light leads to Poynting-Robertson

*E-mail: olgazubko@tut.by

effect and is of the first order v/c where v is the velocity of the body, $c = 3 \cdot 10^{10}$ cm c^{-1} is the speed of light in vacuum. Longitudinal and Doppler effect is also of the first order relative to v/c so it is logical to consider it as well. All other effects listed above are of the order v^2/c^2. If the motion of the body occurs in the neighborhood of the star, which is surrounded by a gas-dust cloud, it is reasonable to take into account space-time curvature and the resulting forces in accordance with general relativity theory (GRT). That leads to additional terms of order v^2/c^2 appearing in the equations of motion.

Light pressure attracts special attention due to the possibility of using it in astronautics as a low thrust engine (solar sails, control of spacecraft using mirrors, etc. [16]–[18]).

The aim of this paper is the integration of relativistic equations of motion of a test body with accounting the effects of SRT and GRT mentioned above. The aim will be achieved by representation of functions in the equations of motion and by representation of functions describing the solutions of these equations of motion as power series taking into account the terms of the order v^2/c^2. Therefore, another significant step will be made in the approximation of the proposed theory of motion of bodies in the two-body problem where one body is the star of mass M, and the second one is the test body of rest mass m_0, to the motions actually existing in the nature. Let us call this approximation the post-Newtonian approximation (PNA) SRT–GRT. Ignoring the effects of PNA GRT, we obtain approximation, which is indeed PNA SRT.

1. Derivation of the equations of motion in PNA SRT-GRT

Consideration of the factors listed above and the assumption, that the star, distribution of medium in the gas-dust cloud surrounding the star, and the particle are spherically symmetric, lead to the conclusion that the motion is *planar*. Without loss of generality, we can assume that the motion of a test body occurs in the Oxy plane of rectangular Cartesian coordinate system $Oxyz$, i.e. in the coordinate plane $z = 0$. According to the investigations described in details in [19]–[26] and using Poincare-Einstein-Infeld approximation method, the equations of motion can be written as (O is the center of masses of the star; $\vec{r}(x; y)$ is radius vector of the center of masses of the test body; $|\vec{r}| = r$; t is the time of distant fixed observer; $\gamma = 6,67 \cdot 10^{-8}$ g^{-1} cm^3 s^{-2} is the Newton's constant of gravitation):

$$\frac{d^2\vec{r}}{dt^2} + \frac{\gamma M}{r^3}\vec{r} = \vec{F_0} + \vec{F_1} + \vec{F_{2э}} + \vec{F_{2g}} + \vec{F_{2\rho}}. \quad (1)$$

The meaning of the quantities in equations (1) is the following. All $\vec{F}$ are specific forces (accelerations) of different orders. Consideration of these forces distinguishes system (1) from the classical (Newtonian) equations of motion of a test body. If there are zeroes on the right side of the equations of motion, then we get:

$$\frac{d^2\vec{r}}{dt^2} + \frac{\gamma M}{r^3}\vec{r} = 0. \quad (2)$$

We introduce the polar coordinate system on the Oxy plane using formulae $x = r\cos\varphi$, $y = r\sin\varphi$ then we find the solutions of the equations of motion (2) using known methods (see e.g. [21]–[24] and the references therein):

$$1/r = (1 + \cos\varphi)/p, \quad (3)$$

which describes conic section with parameter p and eccentricity e.

We will further analyze finite motions in the gravitational field, i.e. $0 \le e < 1$. When deriving orbit equations (3) we used the first two integrals of the system (2): the integral of conservation of energy

$$v^2 = \gamma M (2/r - 1/a), \quad p = a\left(1 - e^2\right) \quad (4)$$

where a is a semi-major axis of elliptical orbit, and v^2 is defined as

$$v^2 = \left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 = \left(\frac{dr}{dt}\right)^2 + r^2\left(\frac{d\varphi}{dt}\right)^2. \quad (5)$$

The formula gives the square of the translational velocity of the test body on the orbit as well as the integral of conservation of orbital momentum of the test body (area integral).

$$L \equiv x\frac{dy}{dt} - y\frac{dx}{dt} = \left|\vec{r} \times \frac{d\vec{r}}{dt}\right| = r^2\frac{d\varphi}{dt} = \sqrt{\gamma M p}. \tag{6}$$

We can take into account the influence of light pressure on the motion of the test body with different degree of accuracy (DA). We mean by this the consideration of terms on the right in the equations of motion (1): 0) do not contain v/c, 1) contain $(v/c)^0$ and v/c in the first degree of accuracy (1DA), 2) contain v^2/c^2, v/c and $(v/c)^0$ (2DA is the second DA).

2. Integration of the equations of motion in the case 0DA

In this case the equation of motion takes the form of (replace $\vec{r}(x;y)$ with $\vec{r^*}(x^*;y^*)$, because the equation of motion and its solution when taking into account light pressure $\vec{F}_0$ differs from formulas (2)–(6):

$$\frac{d^2\vec{r}^*}{dt^2} + \frac{\gamma M}{(r^*)^3}\vec{r}^* = \vec{F}_0 = \frac{\gamma A}{(r^*)^3}\vec{r}^* \tag{7}$$

where A is the *reduced* mass of the star relative to the test body and is defined as (see [13, 14])

$$A = k\sigma_0 W_0 r_0^2/(\gamma m_0 c) \tag{8}$$

where k is the coefficient of light reflection by the test body ($1 \le k \le 2$); σ_0 is the midship section of the body in the reference system K, relatively to which the body is at rest; W_0 is the star constant, i.e. total amount of energy of the electromagnetic radiation of the star in the rest system K. The total amount of energy comes in one second on one square centimeter of fixed in the system K platform, which is perpendicular to the direction of the star and is at a distance r_0 from the star. The quantity $\Pi = k\sigma_0/m_0$ is called *windage* of the test body and for the vast majority of the dust particles (micrometeorites) varies in range

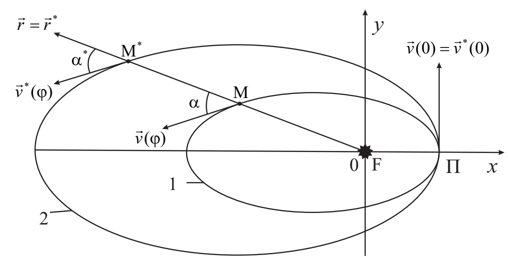

FIG. 1. Possible trajectories of the test body in the photogravitational field (gravity field) of the star with focus F and periastron Π:
1 – unperturbed ellipse in the Newtonian gravitational field;
2 – perturbed ellipse from light pressure

$10^4 \le \Pi \le 10^5$ (see [14, 15, 19]). For example, micrometeorite ice particle of density $0.9\,\mathrm{g\,cm^{-3}}$ and radius $l = 10^{-4}$ cm has $\Pi \approx 10^4\,\mathrm{cm^2\,g^{-1}}$, which in the solar system gives $A \approx 0.1M_\odot$ ($M_\odot = 2\cdot 10^{33}$g is the mass of the Sun).

Integration of the equations of motion (7) is the same as integration of the equations of motion (2). As a result, we have in polar coordinates the following integrals and orbit equation under the same initial conditions for Eqs. (2) and (7) (see [22]).

$$(v^*)^2 = \gamma\,(M - A)\left(\frac{2}{r^*} - \frac{1}{a^*}\right),\ r^{*2}\frac{d\varphi}{dt} = \sqrt{\gamma M p} \tag{9}$$

$$1/r^* = (1 + e^*\cos\varphi)/p^*,\quad p^* = a^*\left[1 - (e^*)^2\right]. \tag{10}$$

When integrating, we have identified the following relationships (see [13, 14]):

$$\frac{p^*}{p} = \frac{M}{M - A} = \frac{1 + e^*}{1 + e},\qquad e^* = \frac{Me + A}{M - A} > e, \tag{11}$$

taking into account (3), (4), (10) we find that $p^* > p, e^* > e, a^* > a$ also $r^* \ge r$ at identical φ, i.e. ellipse (3) under the light pressure has increased in size and turned into the ellipse (10) (or potentially into parabola with $e^* = 1$ or hyperbola with $e^* > 1$ regardless of value of light pressure and "windage" of the test body)(see the figure 1). We will further analyze the ellipses and require the conditions $0 \le e < 1, 0 < e^* < 1$

to be hold. As it follows from (11), the condition $0 < e^* < 1$ will be fulfilled if $A < M(1-e)/2$, which provides $M - A > 0$ (gravitational field). We will call the ellipse (3) as unperturbed, and the ellipse (10) as perturbed. If $e = 0$ than at $A < M/2$ there is always $0 < e^* < 1$, i.e. an unperturbed circumference turns into an ellipse (cf. [13] where it is claimed that circumference remains circumference).

3. Integration of the equations of motion in the case 1DA

We have the equations of motion (see [21], [22]):

$$\begin{aligned} \frac{d^2\tilde{x}}{dt^2} + \frac{\gamma(M-A)}{\tilde{r}^3}\tilde{x} = F_1^x = \frac{\gamma A v^*}{r^{*3}c}\left(-2x^*\cos\alpha^* + y^*\sin\alpha^*\right), \\ \frac{d^2\tilde{y}}{dt^2} + \frac{\gamma(M-A)}{\tilde{r}^3}\tilde{y} = F_1^y = \frac{\gamma A v^*}{r^{*3}c}\left(-2y^*\cos\alpha^* + x^*\sin\alpha^*\right) \end{aligned} \tag{12}$$

where apart from the light pressure (taking into account $\vec{F}_0(F_0^x; F_0^y)$) we take into account also $\vec{F}_1(F_1^x; F_1^y)$ which arises due to the influence of the Doppler effect and the aberration of light; α^* is the angle between the vectors $\vec{v}^* = (dx^*/dt, dy^*/dt)$ and $\vec{r} = (x, y)$ (see the figure 1). Notice also that tilde sign "$\sim$" appears in the equation of motion (12) due to the terms of order v/c, which generalize the equation of motion (7) and therefore modify the solutions of the equations of motion (12) in comparison with the solution of the equation of motion (7).

We apply the same procedure as for finding the first integrals of the equation of motion (7) and after long calculations, which are described in details in the paper [22], we compute the integral of the energy

$$\tilde{v}^2 = \frac{2\gamma M p}{\tilde{r}p^*} + \frac{\gamma M p}{(p^*)^2}\left((e^*)^2 - 1\right) - \frac{2\gamma A}{c\,(p^*)^2}\sqrt{\gamma M p}\left[\left(1 + \frac{3}{2}(e^*)^2\right)\varphi + 2e^*\sin\varphi - \frac{1}{4}(e^*)^2\sin 2\varphi\right] \tag{13}$$

and the integral of the orbital momentum of the test body (area integral)

$$L \equiv \tilde{r}^2\frac{d\varphi}{dt} = \sqrt{\gamma M P} - \frac{\gamma A}{c}\varphi. \tag{14}$$

Computed integral of the energy and the area integral (13) and (14) enable us to derive the orbit equation of the test body. The procedure of obtaining this equation is described in details in the paper of the authors [22]. We will not repeat these calculations here and immediately give the orbit equation in polar coordinates (with the accuracy to the terms of order v/c):

$$\frac{1}{\tilde{r}} = \frac{1 + e^*\cos\varphi}{p^*} + \frac{2\gamma A\varphi}{cp^*\sqrt{\gamma M p}}\left(1 - \frac{e^*}{4}\cos\varphi\right). \tag{15}$$

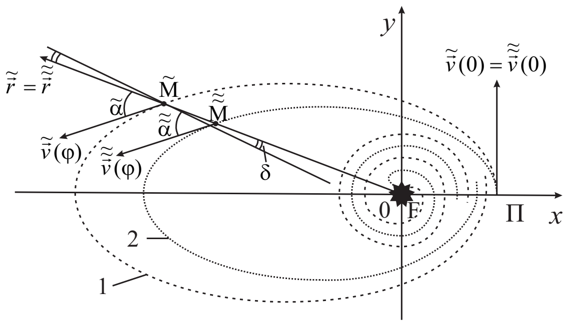

FIG. 2. Possible trajectories of the test body in the photogravitational field (gravity field) of the star with focus F and periastron Π:
1 – spiral trajectory taking into account longitudinal Doppler effect and aberration (PNA SRT of order v/c);δ is the angle of aberration, i.e. angle between $\tilde{v}$ and the direction of the ray of light (in the solar system for the Earth orbit on the average 1 year $\delta \approx 20, 5''$);
2 – trajectory in PNA SRT–GRT of order v^2/c^2.

4. Discussion of the results of integration of the equations of motion in the case 1DA

From (15) it immediately follows that if φ increases, then $1/\tilde{r}$ also increases, i.e. $\tilde{r}$ decreases. It means that the orbit of the test body is indeed a spiral, which twists approaching the star (see the figure 2). The translational velocity $\tilde{v}$ of the motion of the test body is defined by the integral of energy (13). Using (11) and (15) we will change (13) by canceling insignificant terms which are divisible by c. Then

$$\tilde{v}^2 = \frac{\gamma M p}{(p^*)^2}\left(1 + 2e^*\cos\varphi + (e^*)^2\right) + \frac{\gamma A}{c(p^*)^2}\sqrt{\gamma M p}\left(2 - e^*\cos\varphi - 3(e^*)^2\right)\varphi. \tag{16}$$

The last term of order v/c in (16) is positive for $0 < e^* < 2/3$, $\tilde{v}$ increases following the increase of φ. The transformation of electromagnetic radiation into increasing kinetic energy of the test body occurs. For $2/3 < e^* < 1$, the term of order v/c periodically changes the sign, which with the growth of φ leads to the fluctuations of φ with increasing amplitude.

According to the area integral (14), areal velocity $(1/2)\tilde{r}^2(d\varphi/dt)$ of the test body should go to zero and become zero at $\varphi = \varphi_0 = c\sqrt{\gamma M p}/(\gamma A)$ when φ increases. Then the equality $\tilde{r}^2(d\varphi/dt) = 0$ should hold for $\tilde{r} = 0$ or $d\varphi/dt = 0$.

When making calculations in the framework of 1DA we have to take into account only the terms of $(v/c)^0$ and v/c. Using the expressions (10, 14, and 15) we find that for $0 \le \varphi \le \varphi_0$

$$\frac{d\varphi}{dt} = \frac{1}{\tilde{r}^2}\left(\sqrt{\gamma M p} - \frac{\gamma A}{c}\varphi\right) = \frac{1}{(r^*)^2}\left(\sqrt{\gamma M p} - \frac{\gamma A}{c}\varphi\right) + \frac{4\gamma A\varphi}{c r^* p^*}\left(1 - \frac{e^*}{4}\cos\varphi\right) > 0. \tag{17}$$

From (15) and taking into account that for $e^* \ll 1$ we have $p^* \approx r^*$ (see (10)) it follows that

$$\tilde{r} = \left[\frac{1}{r^*} + \frac{2\gamma A\varphi}{c p^*\sqrt{\gamma M p}}\left(1 - \frac{e^*}{4}\cos\varphi\right)\right]^{-1} \approx r^*\left(1 - \frac{2\gamma A\varphi}{c\sqrt{\gamma M p}}\right). \tag{18}$$

An increase of φ from 0 to $\varphi_0/2$ decreases $\tilde{r}$ to zero. Consequently, actual spiral trajectory ends at $\varphi_0/2$ (see figure 2). Taking into account the terms with $e*$ leads to a small variation of function $\tilde{r}(\varphi)$ near the value $\varphi_0/2$. According to (16) for $e^* \ll 1$ we can believe that

$$\tilde{v} = \sqrt{\frac{\gamma M}{p}} \left(1 + \frac{2\gamma A\varphi}{c\sqrt{\gamma M p}}\right). \tag{19}$$

At the moment of the test body falling on the star, that is when $\varphi = \varphi_0/2$, the velocity of the body is $\tilde{v} \approx 2v_0$ where $v_0 = \sqrt{\gamma M/p}$ is the initial velocity of the test body. If, for example, the test body has started its motion on the Earth orbit with initial velocity $v_0 = 30\ \mathrm{km\,s^{-1}}$, then at the moment it reaches the Sun on spiral its velocity is $\tilde{v} \approx 60\ \mathrm{km\,s^{-1}}$. Consideration of the terms with e^* does not change this estimate significantly.

The number of test body revolutions on spiral n_1 around the star until it falls on the star we find using the formula:

$$n_1 = \frac{\varphi}{2\pi} = \frac{\varphi_0}{4\pi} = c\sqrt{\gamma M p}/(4\gamma A\pi). \tag{20}$$

In the above example the spiral around the Sun, on which the micrometeorite moves with the most prevalent characteristic $A \approx 0.1M_\odot$, will make $n_1 \approx 8000$ revolutions (we have used the formula (20) where $p = 1.5 \cdot 10^{13}$ cm).

5. Integration of the equations of motion in the case 2DA

In the equation of motion we add to the right side the terms $\vec{F}_{2э} = (F^x_{2э}; F^y_{2э}), \vec{F}_{2g} = (F^x_{2g};\ F^y_{2g}), \vec{F}_{2\rho} = (F^x_{2\rho};\ F^y_{2\rho})$, which have the form of (see proof in [5, 20, 21]:

$$\begin{aligned} F^x_{2э} &= \frac{\gamma v^{*2} A}{2r^{*3}c^2}\left[\left(3 - 5\sin^2\alpha^*\right)x^* - 3y^*\sin\alpha^*\cos\alpha^*\right], \\ F^y_{2э} &= \frac{\gamma v^{*2} A}{2r^{*3}c^2}\left[\left(3 - 5\sin^2\alpha^*\right)y^* - 3x^*\sin\alpha^*\cos\alpha^*\right] \end{aligned} \tag{21}$$

and arise due to the transverse Doppler effect, the Lorentz contraction of the midship section of the particle and increase in its mass (see [21]);

$$\begin{aligned} F^x_{2g} &= \frac{\gamma(M-A)}{c^2}\left(\left[4\frac{\gamma(M-A)}{r^*} - (v^*)^2\right]\frac{x^*}{(r^*)^3} + \frac{4}{(r^*)^2}\frac{dr^*}{dt}\frac{dx^*}{dt}\right), \\ F^y_{2g} &= \frac{\gamma(M-A)}{c^2}\left(\left[4\frac{\gamma(M-A)}{r^*} - (v^*)^2\right]\frac{y^*}{(r^*)^3} + \frac{4}{(r^*)^2}\frac{dr^*}{dt}\frac{dy^*}{dt}\right) \end{aligned} \tag{22}$$

and due to the space-time curvature caused by the reduced mass of the star (see [19]);

$$\begin{aligned} F^x_{2\rho} &= -\frac{3}{4}\pi\rho\gamma x^* + \frac{4\pi\rho\gamma}{3c^2}\left[4\frac{dx^*}{dt}\left(x^*\frac{dx^*}{dt} + y^*\frac{dy^*}{dt}\right) - x^*(v^*)^2 + \gamma(M-A)x^*\left(-\frac{11}{2r^*} + \frac{3}{R} + \frac{3R^2}{(r^*)^3}\right)\right], \\ F^y_{2\rho} &= -\frac{3}{4}\pi\rho\gamma y^* + \frac{4\pi\rho\gamma}{3c^2}\left[4\frac{dy^*}{dt}\left(x^*\frac{dx^*}{dt} + y^*\frac{dy^*}{dt}\right) - y^*(v^*)^2 + \gamma(M-A)y^*\left(-\frac{11}{2r^*} + \frac{3}{R} + \frac{3R^2}{(r^*)^3}\right)\right]. \end{aligned} \tag{23}$$

Additional $F^x_{2\rho}, F^y_{2\rho}$ describe the acting on the particle of the forces when accounting the reduced mass A of the gravitational field of gas-dust ball with radius R. The center of the ball is in the center of the star and the density of the ball is $\rho = \mathrm{const}$ (see [5]).

Due to the approximation method of integration of the equation of motion (1) we should take into consideration that on the left side of the equation instead of $\vec{r}(x; y)$ we have

$\tilde{\tilde{\vec{r}}}(\tilde{x};\tilde{y})$, on the right side in $\vec{F_0}$ instead of $\vec{r^*}(x^*;y^*)$ (see Eq. (7)) we write $\tilde{\tilde{\vec{r}}}(\tilde{x};\tilde{y})$, and in F_1^x, F_1^y (see the equations of motion (12)) instead of $x^*, y^*, r^*, v^*, \alpha^*$, we have $\tilde{x}, \tilde{y}, \tilde{r}, \tilde{v}, \tilde{\alpha}$ which are already computed in the previous approximations.

Taking all this into account and applying to the equation of motion (1) the method of integration of the equations of motion (12) after long calculations, which are described in details in the paper [27] we compute the integral of the energy with the accuracy to the terms of order v^2/c^2 :

$$(\tilde{\tilde{v}})^2 \approx \tilde{v} + \frac{\gamma A^2\varphi^2}{c^2(p^*)^2}\left(3 - \frac{1}{4}e^*\cos\varphi + 3(e^*)^2\right) - \left[\frac{2\gamma A^2\varphi^2 e^*}{c^2(p^*)^2}\left(1 + e^*\cos\varphi\right) + \frac{2\pi\rho(p^*)^2 e^*}{M-A}\right]\varphi\sin\varphi \tag{24}$$

and compute the area integral

$$(\tilde{\tilde{r}})^2\frac{d\varphi}{dt} = \sqrt{\gamma M p} - \frac{\gamma A}{c}\varphi - \left(\frac{4\gamma(M-A)}{c^2\tilde{r}} - \frac{8\pi\gamma\rho}{3c^2}\tilde{r}^2\right)\sqrt{\gamma M p}. \tag{25}$$

Then we find the orbit and write its equation in polar coordinates leaving only the terms of order v^2/c^2:

$$\frac{1}{\tilde{\tilde{r}}} = \frac{1}{\tilde{\tilde{p}}}\left(1 + \tilde{\tilde{e}}\cos\Phi\right), \quad \tilde{\tilde{p}} = p^*\left(1 - \frac{2\gamma A\varphi}{c\sqrt{\gamma M p}} + \frac{\gamma A^2\varphi^2}{c^2 M p}\right), \tag{26}$$

$$\tilde{\tilde{e}} = e^*\left(1 - \frac{5\gamma A\varphi}{2c\sqrt{\gamma M p}} - \frac{15\gamma A^2\varphi^2}{8c^2 M p} + \frac{3\pi\gamma\rho p^2 e}{c^2 e^*}\varphi^2\right), \tag{27}$$

$$\Phi = \left[1 + \frac{2\pi\rho p^3}{M-A} - \frac{3\gamma(M-A)}{c^2 p} + \frac{21\pi\rho p^2}{c^2} - \frac{6\pi\rho p^3}{c^2 R}\right]\varphi. \tag{28}$$

6. Conclusion

Analysis of the integrals (24), (25) and their solutions (26)–(28) shows that the spiral can be seen as deforming and decreasing in size ellipse, for which the limit equalities $\lim\limits_{\varphi\to\varphi_0/3}\tilde{\tilde{p}} \approx 5p^*/9$, $\lim\limits_{\varphi\to\varphi_0/3}\tilde{\tilde{e}} \approx 0.15e^*$ are held. When taking into account the terms of order v^2/c^2 the test body falls on the star faster than when taking into account the terms of order v/c. When taking into account the terms of order v/c the process is finished approximately for $\varphi_0/2$. If additionally taking into account the terms of order v^2/c^2 then the test body at $\varphi_0/3$ approaches the minimal ellipse with parameter $\tilde{\tilde{p}} \approx 5p^*/9$ and eccentricity $\tilde{\tilde{e}} \approx 0.15e^*$. Therefore the body will make $n_2 \approx$ 5330 revolutions.

References

[1] A.P. Rayabushko. Equations of motion of rotating masses in general relativity theory. Zhurnal ecsperementalnoy i teoreticheskoy

fizhiki. **33**, 1387-1395 (1957). (In Russian).

[2] N. M. Petrova, Z.A. Aynikeeva. About system of spherically symmetric bodies in general relativity theory. In: *Issledovaniya processov perenosa. Voprosy teorii otnositelnosti. Trudy Kazashskogo universiteta.* (Alma-Ata, 1959). Pp. 209-229. (In Russian).

[3] N. M. Petrova, I. B. Sandina. The method of obtaining the equations of motion in general relativity theory. Fizika (J. of Kazan state university). **4**, 14-16 (1970). (In Russian).

[4] A.P. Raybushko. *The motion in general relativity theory.* (Vyshaya shkola, Minsk, 1979). (In Russian).

[5] A.P. Raybushko, I.T. Nemanova. Relativistic effects of the motion of test bodies in the gas-dust bowl with attracting center. Doklady AN BSSR. **28**, 806-809 (1984). (In Russian).

[6] M.M. Abdilin. The research of the problem of motion of bodies in general relativity by the Fock method. (AN BSSR, Minsk, 1985). (In Russian).

[7] A.P. Raybushko. The problem of stability of motion of bodies in general relativity theory. (Vyshaya shkola, Minsk, 1987). (In Russian).

[8] A.P. Raybushko, T.A. Zhur, I.T. Nemanova. Motion of bodies and its stability in GRT. In: *The Sun, the Stars, The Universe and General Relativity*, the conference proceeding in honor of Ya.B. Zeldovich 95th Anniversary, Minsk, Belarus on April 20-23, 2009. (AIP, Melville, New York, 2010). Vol. 1205. Pp. 148-154.

[9] L.M. Chechin. *The motion of bodies in classical gauge fields.* (Lambert Academic Publishing, Deutschland, 2012). (In Russian).

[10] A. Einstein. *The complete collection of scientific papers.* (Nauka, Moscow, 1965). Vol. 1-2. (In Russian).

[11] L.Infeld, J.Plebanski. *Motion and Relativity.* (Warshawa, 1960).

[12] V.A. Fok. *Theory of space-time and gravity.* (Fizmatgiz, Moscow, 1961). (In Russian).

[13] V.G. Fesenkov. *The meteoric matter in the interplanetary space.* (AN SSSR, Moscow, 1947). (In Russian).

[14] D.Y. Martynov. *The course of general astrophysics.* (Moscow, 1988). (In Russian).

[15] V.V. Radzievskiy. The Solar System. In: *Fizika kosmosa.* (Moscow, 1976). Pp. 61-80. (In Russian).

[16] R.Ya. Kezerashvili, J.F. Vazquez-Poritz. The Poynting-Robertson Effect on Solar Sails. In: *Proc. of the Second International Symposium on Solar Sailing, 20-22 July 2010.* (New York, USA, 2010). Pp. 157-162.

[17] Sheng-Ping Gong, Jun-Feng Li, Xiang-Yuan Zeng. Utilization of an H-reversal trajectory of a solar sail for asteroid deflection. RAA Journal. **11**, 10 (2011).

[18] E.N. Polyahova. *The space flight with a solar sail.* (Moscow, 2011). (in Russian).

[19] A.P. Ryabushko, T.A. Jour, I.P. Boyarina. The newtonian motion of the body, taking into account the light pressure. Vestsi NAN Belarusi. Ser. fiz.-mat. **3**, 80-88 (2011). (in Russian).

[20] A.P. Ryabushko, T.A. Jour, I.P. Boyarina. The motion of the body, taking into account the light pressure in the post-Newtonian approximation of the general relativity theory. Vestsi NAN Belarusi. Ser. fiz.-mat. **4**, 93-97 (2011). (In Russian).

[21] A.P. Ryabushko, T.A. Jour, I.P. Boyarina. The equations of motion of the body, taking into account the light pressure in the special and general theories of relativity. Vestsi NAN Belarusi. Ser. fiz.-mat. **3**, 77-83 (2012). (In Russian).

[22] A.P. Ryabushko, T.A. Jour, I.P. Boyarina. Relativistic first integrals and the trajectory of the body, taking into account the light pressure. Vestsi NAN Belarusi. Ser. fiz.-mat. **4**, 89-95 (2012). (In Russian).

[23] A.P. Ryabushko, T.A. Jour, I.P. Boyarina, O.L.Zubko, V.I.Yurinok. The effect of the light pressure on the relativistic motion of bodies. In: *XI Belorusskaya matematicheskaya konferenciya.* (Minsk, 2012). Vol. 3. Pp. 48-50. (In Russian).

[24] A.P. Ryabushko, T.A. Jour, I.P. Boyarina, O.L.Zubko. Relativistic first integrals and the trajectory of the body, taking into account the light pressure. Noveyshie dostizeniya evropeyskoy nauki. **18**, 30-38 (2012). (In Russian).

[25] A.P. Ryabushko, I.T. Nemanova, T.A. Jour. The metric Riemannian space-time generated by inhomogeneous surroundings with an attractive center. Vestsi NAN Belarusi. Ser. fiz.-mat. **1**, 96-100 (2012). (In Russian).

[26] A.P. Ryabushko, I.T. Nemanova, T.A. Jour. The motion of a test body in a Riemannian space-time generated by inhomogeneous surroundings with the attracting center. Vestsi NAN Belarusi. Ser. fiz.-mat. **2**, 89-92 (2012). (In Russian).

[27] O.L. Zubko. Relativistic effects of motion of particle in photogravitational field of star. Vestnik BSU. **1**, 3 (2014). (In Russian).